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The assessment and reduction of carbon oxides emissions at electric arc furnaces - Essential factors for sustainable development

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Abstract

Carbon oxides (CO_x) have a negative impact on the steelworkers, environment and populations. The aim of this paper is to assess the CO_x emissions from steelmaking in the electric arc furnaces, in order to improve the gaseous emissions management, an essential factor for sustainable development, by identifying the most polluting technological stages of this process. The experimental researches were carried out on two electric arc furnaces with alkaline lining. The measurement of CO_x emissions was performed using a Maxilyzer computer for burned gases automated analysis. After evaluating the emissions of CO_x during steelmaking in electric arc furnaces, it results that: the most significant emissions have been generated at the end of the melting and refining stage; in terms of pollution by CO_x, the most polluting stages are melting and refining; the level of CO_x emissions from electric arc furnaces depends on the carbon content of material input. The reduction of CO_x emissions to the steelmaking in the electric arc furnaces is possible by charge component selection and by the use of raw materials with reduced carbon content.

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1. Introduction

One of the most important sources of carbon oxides emissions from the ferrous metals industry includes electric arc furnaces [1].

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The steelmaking in the electric arc furnace belongs to the category of the industrial processes with high degree of pollution because the following pollutant substances are transferred in the air environment factors: carbon oxides, sulphur oxides, nitrogen oxides, volatile organic compounds (VOC), particulate matter, dioxins and furans [2].

Carbon oxides have a negative impact on the steelworkers, environment and populations. The carbon monoxide is a pollutant having an asphyxiation effect, resulting from incomplete combustion. It combines with hemoglobin to form carboxyhemoglobin, resulting in hypoxia with serious consequences for various tissues and cell respiration, which is manifested clinically by headache, dizziness, drowsiness, nausea, arrhythmias etc. Carbon monoxide plays a role in ozone formation. It is also transformed in carbon dioxide, which is also directly emitted when fuels are being burnt. Carbon dioxide is the most abundant anthropogenic greenhouse gas emitted through human activities and has no direct adverse health effects. Carbon dioxide is naturally present in the atmosphere as part of the Earth's carbon cycle and come from a variety of natural sources. Human-related emissions are responsible for the increase that has occurred in the atmosphere since the industrial revolution [3,4,5,6].

The assessment and reduction of carbon oxides emissions play a key role in terms of sustainable development and environmental protection [1,2,7,8].

Sustainable development has been defined as “development that meets the needs of the present without compromising the ability of future generations to meet their needs”. With other words, sustainable development is the development that contribute at increasing the life and the environment quality [9,10,11,12,13].

Concept of sustainable development in the steel industry depend on economic, social and environmental indicators. The International Iron and Steel Institute [14,15] have suggested a number of sustainability indicators to measure environmental, economic and social performance for steel industry. One of the environmental indicators is represented by greenhouse gases [16]. Carbon oxides are categorized as greenhouse gas emissions.

Sustainable development to the steelmaking in the electric arc furnaces, involves:

- conserving the natural resources such as iron ore, coal, dolomite, magnesite etc.;
- reducing the emissions of carbon oxides;
- reducing the emissions of nitrogen oxides;
- reducing the emissions of sulphur oxides;
- reducing the other gaseous emissions such as volatile organic compounds (VOC);
- reducing the quantity of wastes landfilled;
- recovery the valuable components from the wastes;
- increasing the degree of recycling of dust and slag;
- reducing the quantity of hazardous wastes.

The aim of this paper is the assessment of carbon oxides (CO_x) emissions to the steelmaking in the electric arc furnaces. From the industrial / technical point of view it is important to assess the carbon oxides emissions from steelmaking in the electric arc furnaces in order to identify the most polluting technological stages and to reduce the concentration of these pollutants.

The objectives of the paper are:

- the assessment of the carbon oxides emissions (COx) at two electric arc furnaces;
- establishing the evolution of carbon oxides emissions (COx) for each technological stage specific to the steelmaking in the electric arc furnaces;
- the identification of the carbon oxides (COx) emitting sources to the steelmaking in the electric arc furnaces;
- establishing methods to reduce carbon oxides emissions (COx) to the steelmaking;

2. Potential Sources that Generate the Carbon Oxides (CO_x) to Steelmaking in the Electric Arc Furnaces

The sources with carbon oxides generating potential to the steelmaking are [1,2]:

- the carbon from the charge;
- scrap iron;

- first fusion pig iron;
- fuel material;
- the carbon from the graphite electrodes, which are gradually consumed, until destruction.

The carbon oxidation in the metal bath can be performed by direct reaction with oxygen and through the iron oxide. The chemical reactions that lead to the generation of carbon oxides (CO_x) to the steelmaking in electric arc furnaces are [1,2,17]:

$$[C]+[O]=\{CO\} \tag{1}$$

$$[C]+[FeO]=[Fe]+\{CO\} \tag{2}$$

$$[C]+2[FeO]=2[Fe]+\{CO_2\} \tag{3}$$

$$[C]+\{O_2\}\leftrightarrow\{CO_2\} \tag{4}$$

At high temperatures, the following reactions can also occur:

$$5[C]+([P_2O_5])=5\{CO\}+2[P] \tag{5}$$

$$2[C]+([SiO_2])=[Si]+2\{CO\} \tag{6}$$

$$[C]+([MnO])=\{CO\}+[Mn] \tag{7}$$

In the slag, the following CO emitting reactions take place:

$$3(C)+(CaO)=(CaC_2)+\{CO\} \tag{8}$$

$$3(FeS)+(CaC_2)+2(CaO)=3(CaS)+3[Fe]+2\{CO\} \tag{9}$$

$$(CaCO_3)\leftrightarrow\{CO_2\}+(CaO) \tag{10}$$

$$2(C)+\{O_2\}=2\{CO\} \tag{11}$$

The reduction of carbon oxides emissions to the steelmaking in the electric arc furnaces is possible by [1,2,18,19]:

- the charge component selection;
- the use of raw materials with reduced carbon content;
- using "foaming slag" technology.

The foaming slag can be obtained at the end of fusion of ferrous materials before the disappearance of the last melt by simultaneously injecting through the cleaning door of the:

- coal in the slag;
- oxygen at the surface or inside the metal.

The foaming slag is not stable, once formed, is degrading, as a consequence the coal must be continuously injected. This technology has the following effects:

- decreasing the air flow rate entering the furnace, which results in lower emissions of carbon oxides;
- decreasing the melting stage duration;
- decreasing of the graphite electrodes consumption.

3. Material and Method

The experimental researches were carried out on two electric arc furnaces with alkaline lining. The type of steel produced in both furnaces was carbon steel.

The measurement of carbon oxides (COx) emissions was performed using a Maxilyzer computer for burned gases automated analysis.

The measurement of carbon oxides (CO_x) emissions was performed every 20 minutes, during the technological stages of the steelmaking in the electric arc furnaces. The technological stages of steelmaking have had the following durations: melting - 150 minutes; refining - 60 minutes; desulphurization and deoxidizing - 30 minutes.

The results obtained from experimental researches were compared with the allowed values for these pollutants at emissions, specified in the references [20,21].

4. Results and Discussions

In Figures 1 and 2 there are presented the emissions of carbon monoxide (CO) and maximum carbon monoxide (CO max) recorded during the technological stages specific to the steelmaking process in the electric arc furnaces with a capacity of 10 tons, and 30 tons respectively.

Figure 1 shows that the values recorded for carbon monoxide are a bit over the allowed limit. The highest values recorded for carbon monoxide were at the end of melting stage (125 ppm) and at the beginning of the refining stage (119 ppm). This is due to the fact that at the end of the melting stage, the temperature of the metal bath has a steep increase rate and the oxygen dissolved in the metal bath in the form of FeO, triggers the oxidation of carbon reaction in all the metal bath, which results in the generation of carbon monoxide (CO) and its elimination in the atmosphere.

The highest values recorded for the maximum carbon monoxide (CO max) were at the end of the melting stage (921 ppm) and at the beginning of the refining stage (890 ppm). In this case one can assess that if the steel is produced in the 10 tonnes oven, the maximum allowed concentration of carbon monoxide is exceeded by 10.55 times at the end of the melting stage and by 10.19 times at begining of the refining stage.

Figure 2 shows that the values recorded for carbon monoxide (CO) and carbon monoxide maximum (CO max) are over the allowed limit. The highest values for emissions were recorded at the end of melting stage (minute 140) and at the beginning of the refining stage (minute 160). Thus, the maximum allowed concentration is exceeded by 2.30 times at the end of melting stage and by 1.38 times at the beginning of the refining stage. Towards the end of refining stage one can observe a significant decrease of the recorded values for carbon monoxide.

The emissions of maximum carbon monoxide (CO max) recorded exceed the maximum allowed concentration by 15.12 times at the end of melting stage and by 13.79 times at the beginning of the refining stage.

Figure 3 presents a comparative analysis between the emissions of carbon monoxide (CO) recorded during the technological stages of steelmaking in the electric arc furnaces with a capacity of 10 tons and 30 tons respectively.

Figure 3 shows that the values recorded for carbon monoxide exceed the allowed limit. The highest values recorded for carbon monoxide were at the end of melting stage, that is 201 [ppm] for the electric furnace with the capacity of 30 tons and 125 [ppm] for the electric furnace with a capacity of 10 tons.

At the beginning of the refining stage, the carbon monoxide concentration for the 30 tons furnace was 121 [ppm], and for the 10 tons furnace it was 119 [ppm]. After that, there was a significant decrease in the recorded concentrations of carbon monoxide, due to the fact that the decarburization metal bath was done almost completely and the desired percentage of carbon was reached.

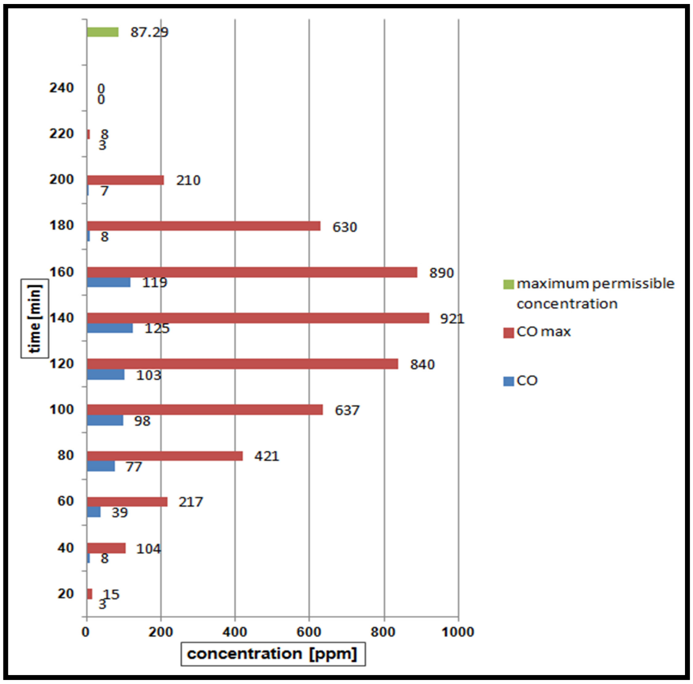

Fig. 1. The carbon monoxide (CO) and maximum carbon monoxide (CO max) emissions variations to the electric arc furnace having the capacity 10 tons

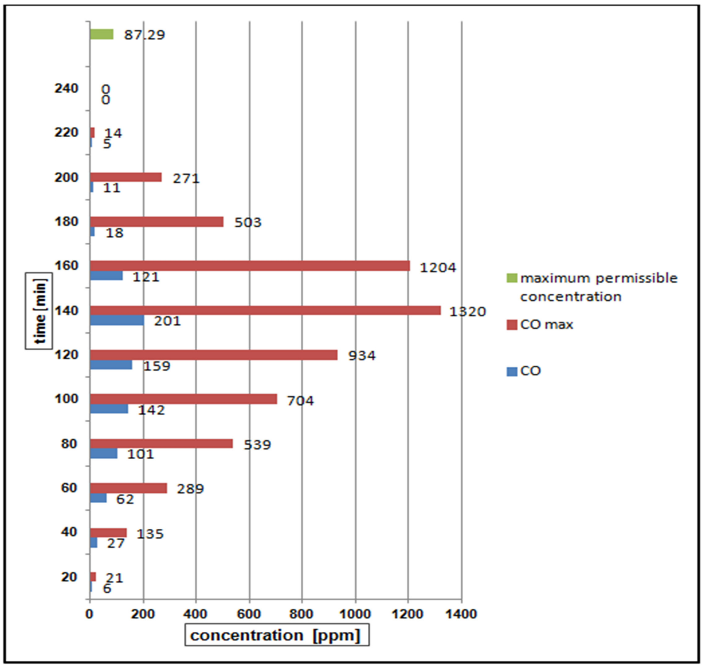

Fig. 2. The carbon monoxide (CO) and maximum carbon monoxide (CO max) emissions variations to the electric arc furnace having the capacity 30 tons

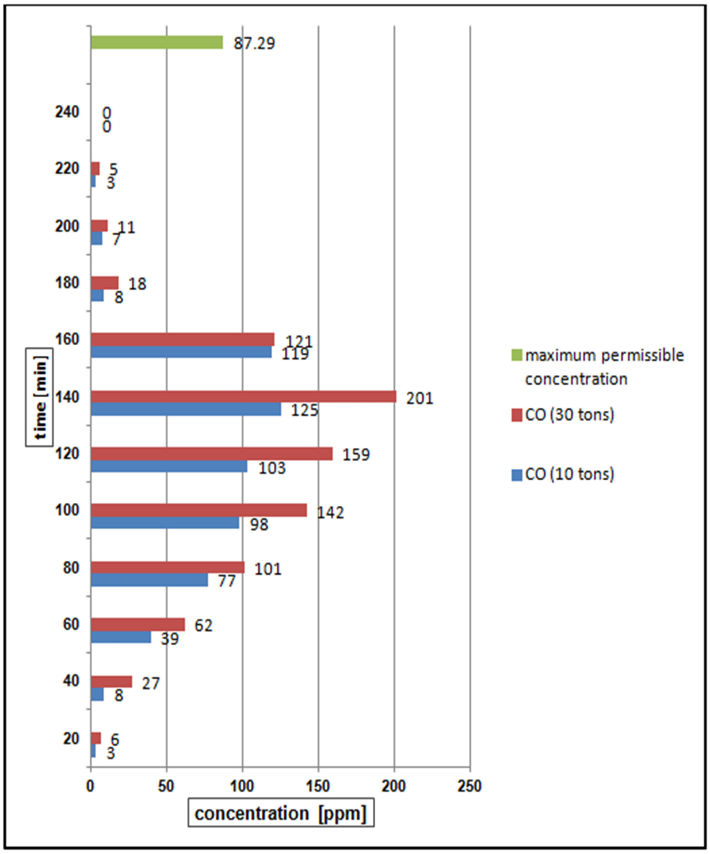

Fig. 3. The carbon monoxide (CO) emissions variations from the electric arc furnace having the capacity of 10 tons and 30 tons respectively

Figure 4 presents a comparative analysis between the maximum emissions of carbon monoxide (CO max) recorded during the technological stages of steelmaking in the electric arc furnaces with a capacity of 10 tons and 30 tons respectively.

According to the data presented in Figures 1, 2, 3 and 4 the carbon monoxide is generated through the process of steelmaking in electric arc furnaces, and the maximum allowed emission concentration is exceeded by around 11 times for the 10 tons furnace and by 15 times for 30 tons furnace. The carbon monoxide concentrations begin to increase as the charge goes from the solid state to the liquid state. The technological stages during which there are generated significant amounts of carbon monoxide are the end of melting stage and the beginning of the refining stage. Towards the end of the melting stage the temperature of the metal bath has high growth rate, the oxygen dissolved in the metal bath, in the form of FeO, triggers the oxidation reaction of carbon in the all liquid steel, resulting in the generation of carbon monoxide (CO) and its elimination from the metal bath, through slag, directly in the atmosphere. One can observe that, by the end of refining stage, the carbon monoxide concentrations begin to decline in both furnaces.

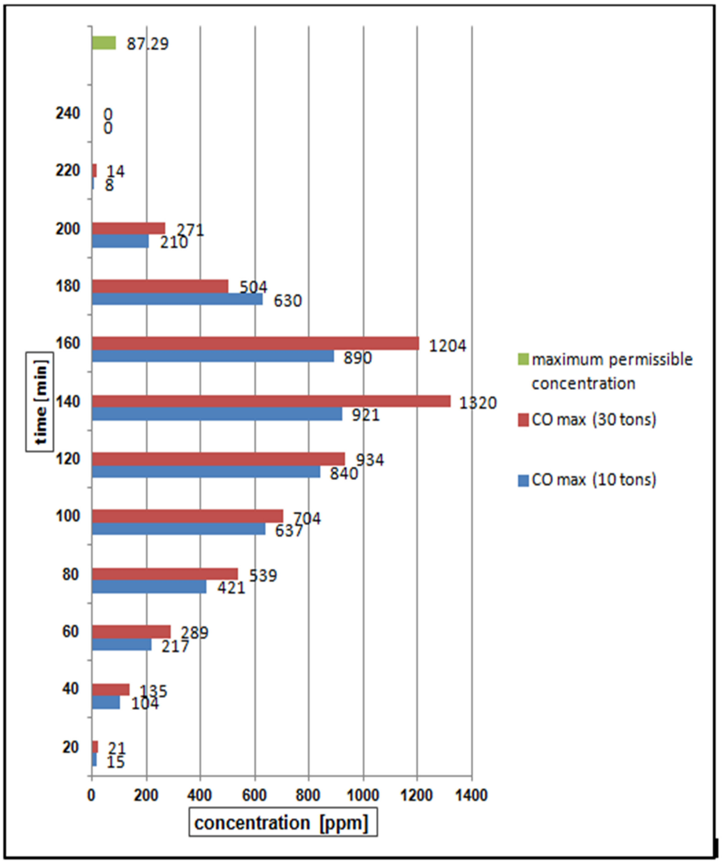

Fig. 4. The maximum carbon monoxide (CO max) emissions variations from the electric arc furnace having the capacity of 10 tons and 30 tons respectively

5. Conclusions

The carbon oxides (CO_x) have a negative impact on the environment in general and particularly on the quality of the air environmental factor, being responsible for global warming. The negative impact of carbon oxides (CO_x) have an effect on the steel workers and on the population.

The added value of the research is the assessment and reduction of carbon oxides emissions at two electric arc furnaces with alkaline lining.

The most polluting technological stages to the steelmaking in the electric arc furnaces, from the point of view of carbon oxides emissions, are melting and refining. After this technological stages, it was recorded a significant reduction in the level of carbon oxides emissions.

The potential sources that generate the carbon oxides (CO_x) emissions to steelmaking are: the carbon contained in charge components, such as old scrap, first fusion pig iron, fuel materials and the carbon contained in the graphite electrodes.

The level of carbon oxides emissions, during steelmaking in electric arc furnaces is influenced by the carbon content of the charge components.

The carbon oxides emissions recorded at the electric arc furnace having the capacity of 30 tons are higher than those recorded in the furnace having the capacity of 10 tons with 30-40%.

The pollution prevention and control techniques to reduce the air pollution with carbon oxides (CO_x) to the steelmaking includes the following: the charge component selection; the use of raw materials with reduced carbon content; using "foaming slag" technology. This technique of "slag foaming" has the effect of: reducing airflow entering the furnace; decreasing the melting stage duration; decreasing the consumption of the graphite electrodes, which results in lower emissions of carbon oxides.

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